Marshall Space Flight Center

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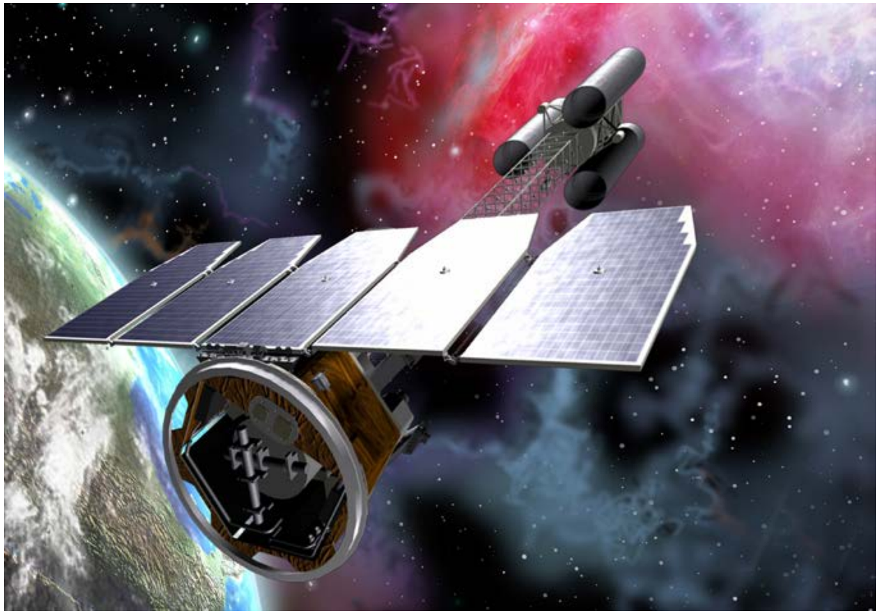
IXPE
Imaging
X-Ray
Polarimetry
Explorer

Optics for the Imaging X-ray Polarimetry Explorer

Brian Ramsey NASA/MSFC

For the IXPE Team

The Imaging X-Ray Polarimetry Explorer *IXPE*



IXPE is a NASA Small Explorer Mission dedicated to X-ray polarimetry – the first of its kind – opening up the field of imaging polarimetry

It was selected in January 2017 for a flight in 2020/2021

IXPE ADDRESSES KEY SCIENTIFIC OBJECTIVES

- **Addresses key questions, providing new scientific results and constraints that trace back to the Astrophysics Roadmap and the Decadal Survey**
  - What is the spin of a black hole?
  - What are the geometry and magnetic-field strength in magnetars?
  - Was our Galactic Center an Active Galactic Nucleus in the recent past?
  - What is the magnetic field structure in synchrotron X-ray sources?
  - What are the geometries and origins of X-rays from pulsars (isolated and accreting)?
- **Provides powerful and unique capabilities**
  - Reduces integration time by a factor of 100 over our OSO-8 experiment
  - Simultaneously provides imaging, energy, timing, and polarization data
  - Devoid of instrument systematic effects at less than a fraction of a percent
  - Meaningful polarization measurements for a large number of sources of different classes, as evidenced by our Design Reference Mission

IXPE Team and Mission

Institutional Roles and Responsibilities

Institution	Role
NASA Marshall Space Flight Center	PI team, project management, SE and S&MA oversight, mirror module fabrication, X-ray calibration, science operations, and data analysis and archiving
agenzia spaziale italiana	Detector system funding, ground station
Ball	Spacecraft, payload structure, payload, observatory I&T
iaps, INAF Istituto Nazionale di Astrofisica National Institute for Astrophysics, INFN	Polarization-sensitive imaging detector systems
CU, LASP	Mission operations
Roma Tre Università degli Studi, Stanford University	Scientific theory
McGill	Science Working Group Co-Chair
Massachusetts Institute of Technology	CoI

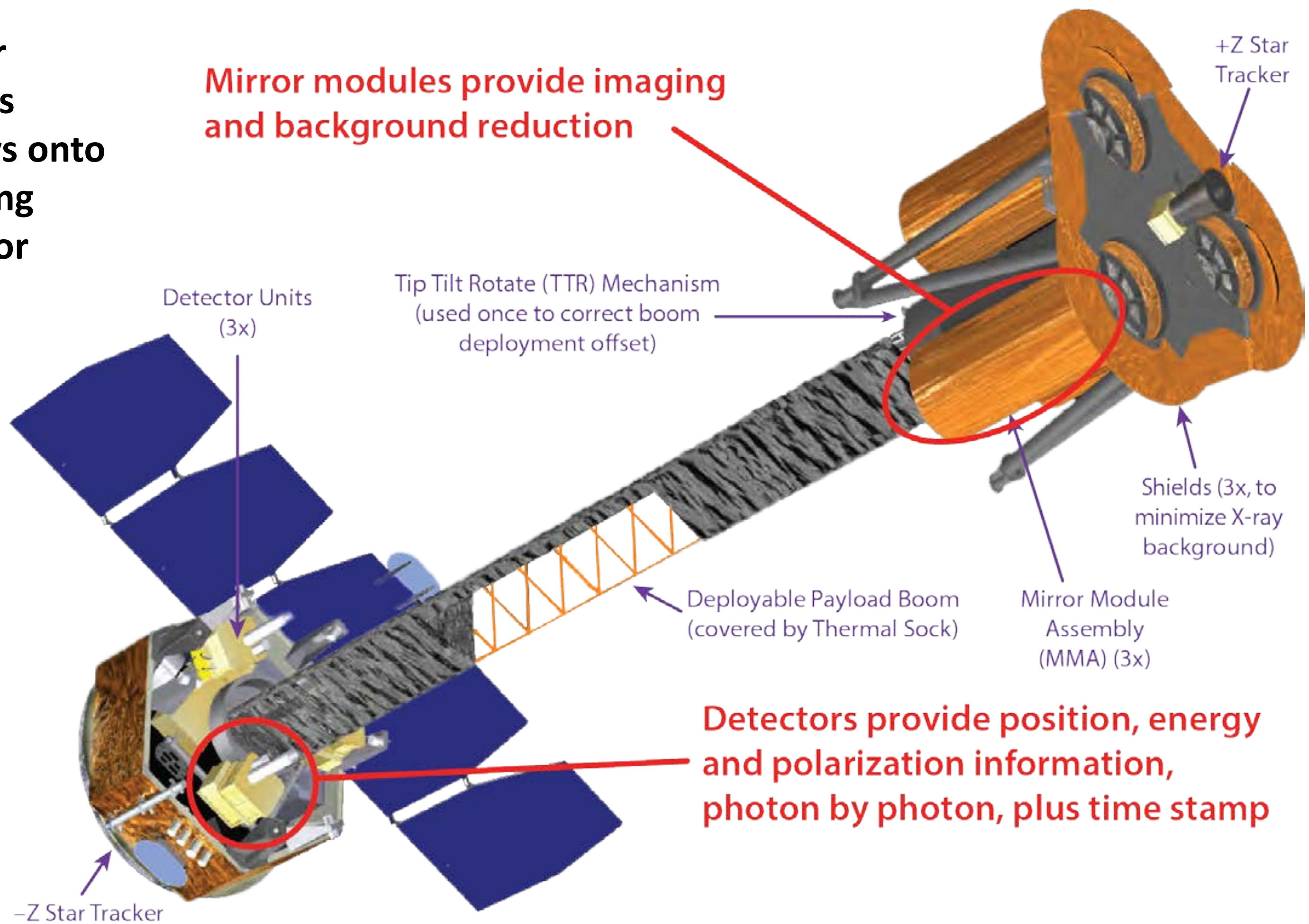
Science Advisory Team

Mission Design and Operations

- Pegasus XL launch from Kwajalein
- 540-km circular orbit at 0° inclination
- 2 year baseline mission, 1 year SEO
- Point-and-stare at known targets
- Science Operations Center at MSFC
- Mission Operations Center at CU/LASP
- Malindi ground station (Singapore Backup)
- Launch ready by end of 2020

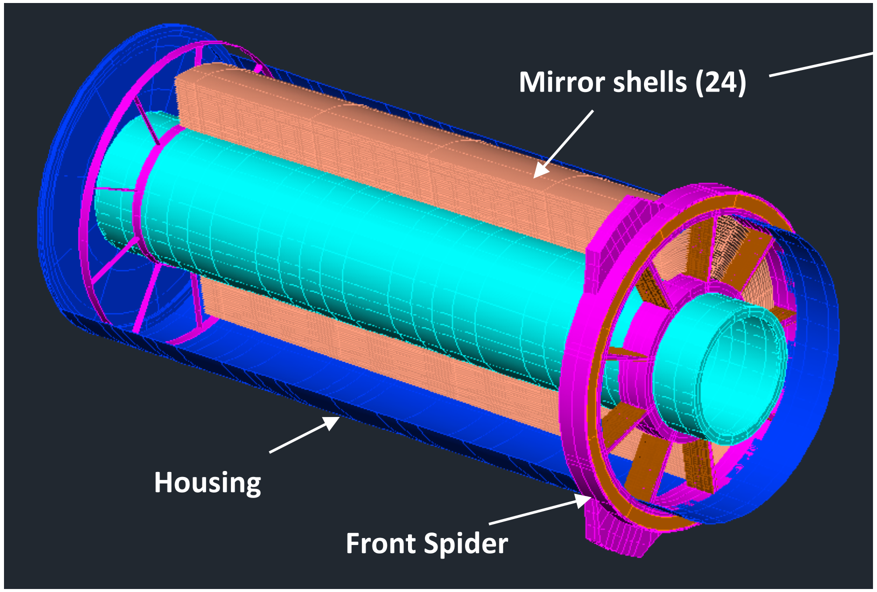
Payload Overview

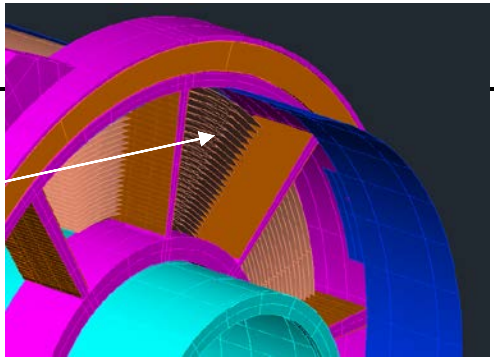
Set of three mirror module assemblies (MMA) focus x rays onto three corresponding focal plane detector units



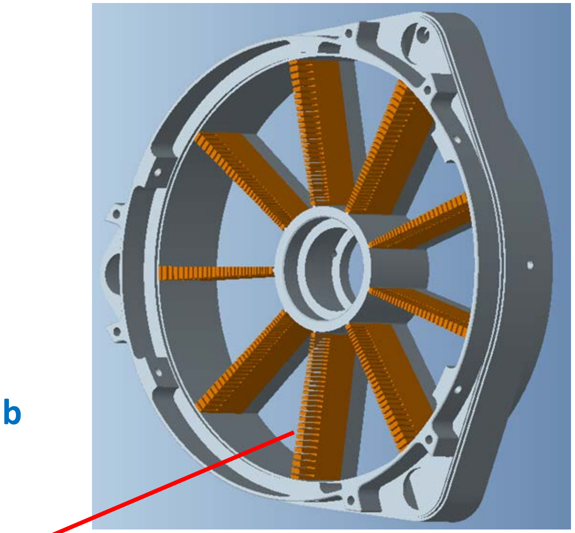
Mirror Module Assembly

IXPE Mirror Module Assembly





Front Spider



Shell Mounting Comb

Design approach

- Uses a single rigid spider to support the 24 nested shells and attach module to structure.
- Light weight housing mainly for thermal control
- Limit (rear) spider does not support mirror shells but limits their vibrations during launch.
- Mounting combs provide shell attachment points

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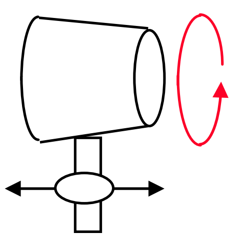
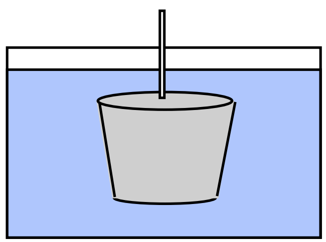
Mirror Shell Fabrication – Electroformed Replication

Mandrel Fabrication

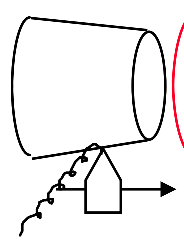
1. Machine mandrel from aluminum bar



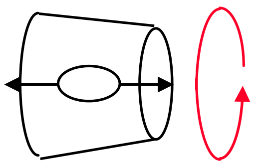
2. Coat mandrel with electroless nickel (NiP)



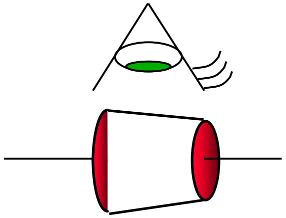
3. Diamond turn mandrel for sub-micron figure



4. Polish mandrel to 0.3-0.4 nm rms

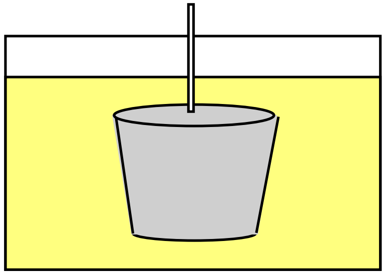


5. Metrology on mandrel

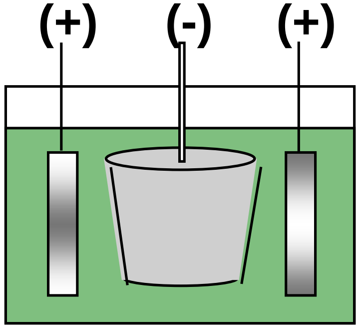


Mirror Shell Fabrication

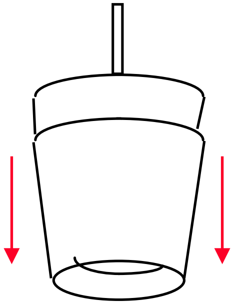
6. Passivate mandrel surface to reduce shell adhesion



7. Electroform Nickel/Cobalt shell on to mandrel



8. Separate shell from mandrel in cold water bath



NiCo electroformed mirror shells

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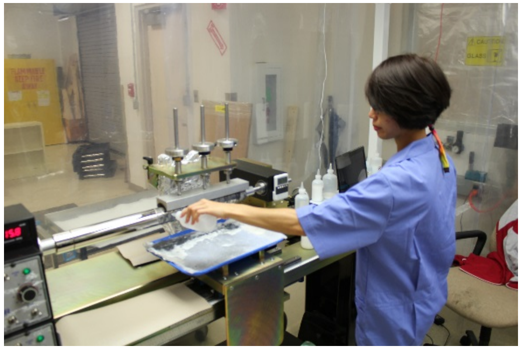
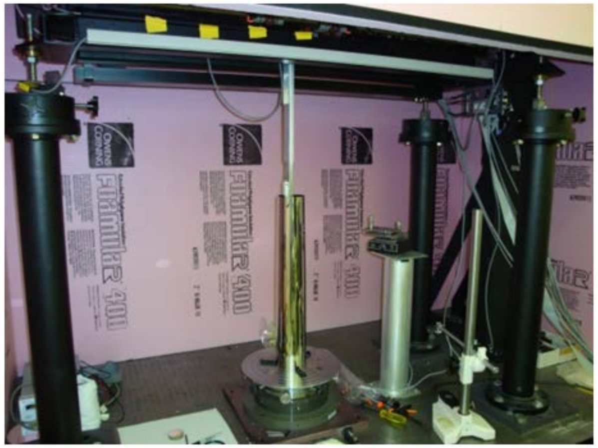
MSFC Infrastructure for X-ray Optics Fabrication

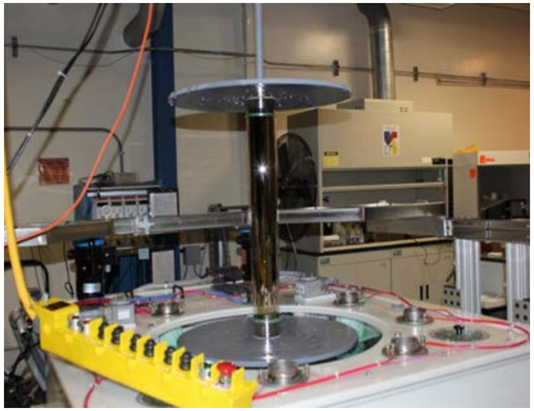
Mandrel diamond turning



Mandrel polishing



Mandrel and shell metrology

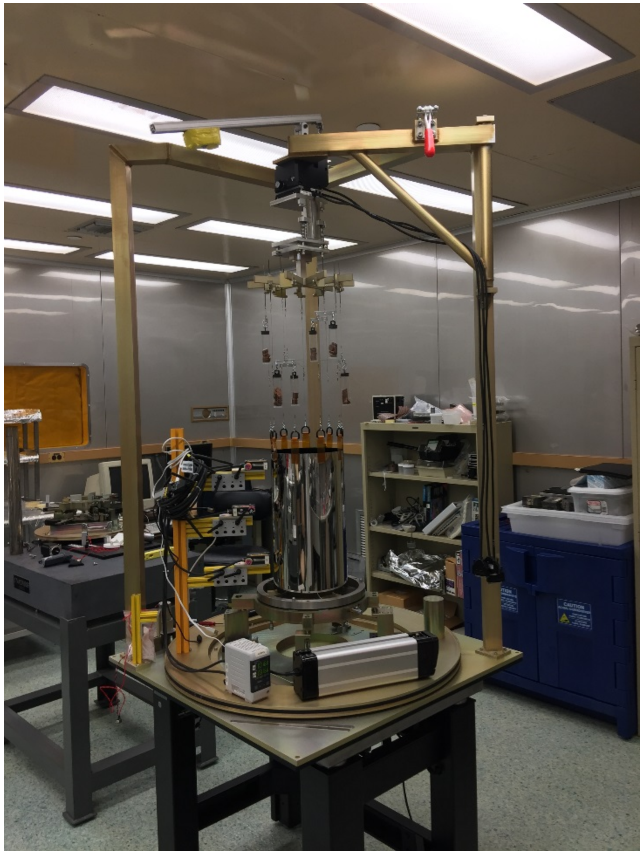


Nickel/Cobalt shell electroforming

X-ray testing and calibration

Mirror Shell Integration and Alignment

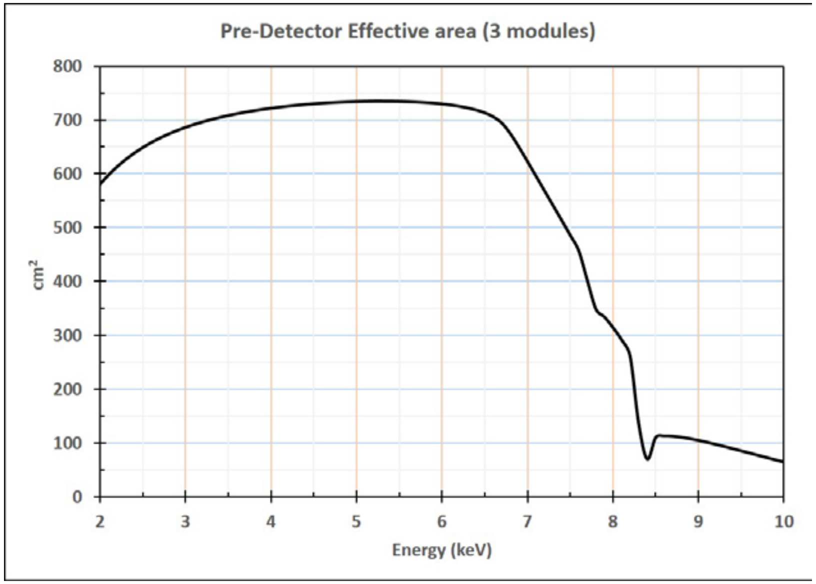
- Shell assembly proceeds from the inner shell outwards
- The assembly system holds each successive shell on a system of wires that can be moved radially and adjusted in tension.
- Keyence proximity sensors rotate around the hanging shell and measure radial displacements of the mirror external surface
- Software takes the displacement data as a function of rotation angle and fits various curves (and calculate various performance parameters) to aid in the alignment process.
- When shell performance is satisfactory, it is glued into the spider comb and the next shell is mounted



Integration System

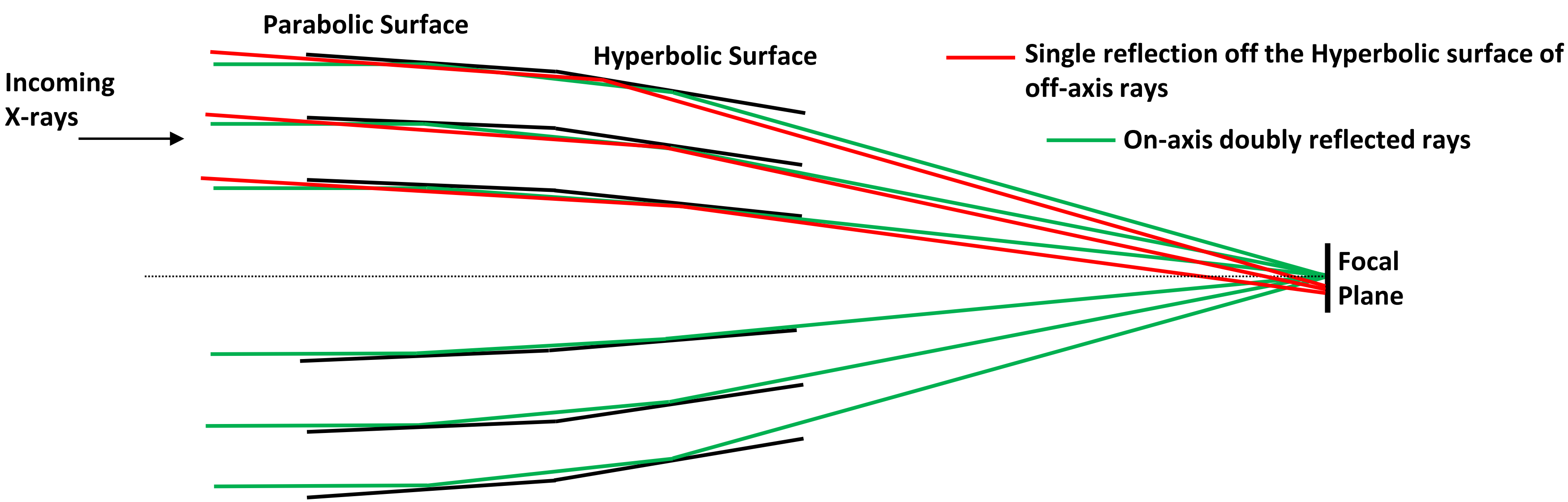
Mirror Module Assembly Properties

Property	Value
Number of modules	3
Mirror shells per module	24
Inner, outer shell diameter	162, 272 mm
Total shell length	600 mm
Inner, outer shell thickness	180, 260 µm
Shell material	Nickel cobalt alloy
Effective area per module	210 cm^2 (2.3 keV) > 230 cm2 (3-6 keV)
Angular resolution	≤ 25 arcsec HPD
Detector limited FOV	12.9 arcmin
Focal length	4 m
Mass (3 assemblies)	95 kg with contingency



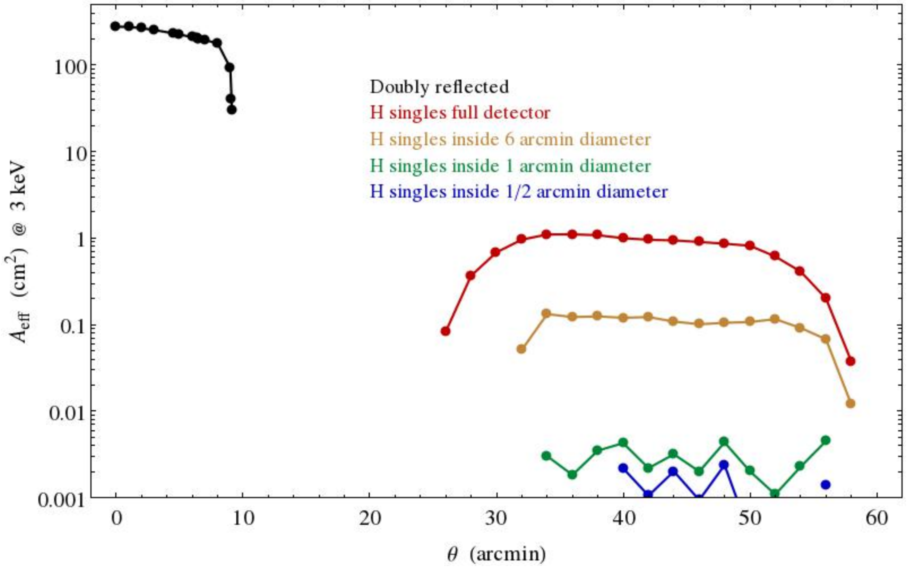
GHOST RAY ANALYSIS

- Radiation from outside the instrument field of view can reflect off the mirror shells, end up in the detector, and constitute a background
  - This typically arises from single reflections from either the hyperbolic or parabolic segment of the mirror (depends on exact module geometry)
  - For IXPE, only single reflections from the hyperbola (H singles) contribute



GHOST RAY ANALYSIS

- Ray trace analysis was performed



- Results of IXPE MMA stray radiation analysis:
  - Stray radiation reaching detector is from a small annulus of the sky from 25 arcminutes off axis to just under 60 arcmin.
  - Peak magnitude (effective area) is ~ 300 x lower than the on-axis signal, <u>integrated over the whole detector.</u>
    - Imaging further reduces this by a large amount (see above figure)

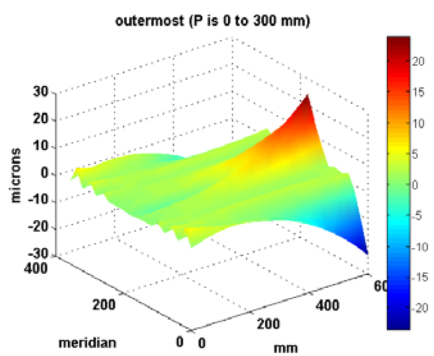
Ghost Ray Analysis

- Are there any very bright sources within 25 to 60 arcminute of an intended target that could increase the background for that observation?
- Not a problem for point sources as stray radiation is reduced by more than factor of 10^5
- What about extended sources ?
  - Use the MAXI (Monitor of All-sky X-ray Image) catalog of sources, appropriate for the IXPE energy range, to search around IXPE design reference mission targets
    - The only source affected is SGR B2, due to the bright source SAXJ1747-285 nearby. However, the imaging properties of IXPE will isolate this stray radiation at the edge of the detector, away from the target.

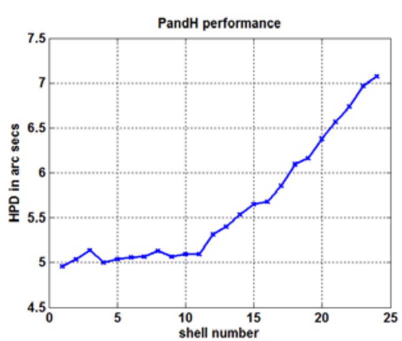
THERMAL REQUIREMENTS

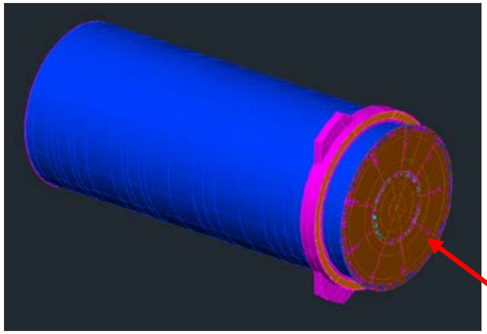
- Thermal requirements derived from FEA analysis and subsequent ray tracing.
    - Looked at temp variations across mirror diameter and along axis.
        - Most sensitive to temp gradients from one side of mirror to other
            - Set requirements of max 2 °C variation across mirror assembly
            - Achieved with ~ 10 W orbit average power per module

Example of mirror shell distortions for 2°C change across mirror diameter



Affect of this on mirror shell performance





Thermal model of mirror module assembly.

Entrance and exit aperture thermal shields: 1.4 micron polyimide coated with 300 A aluminum

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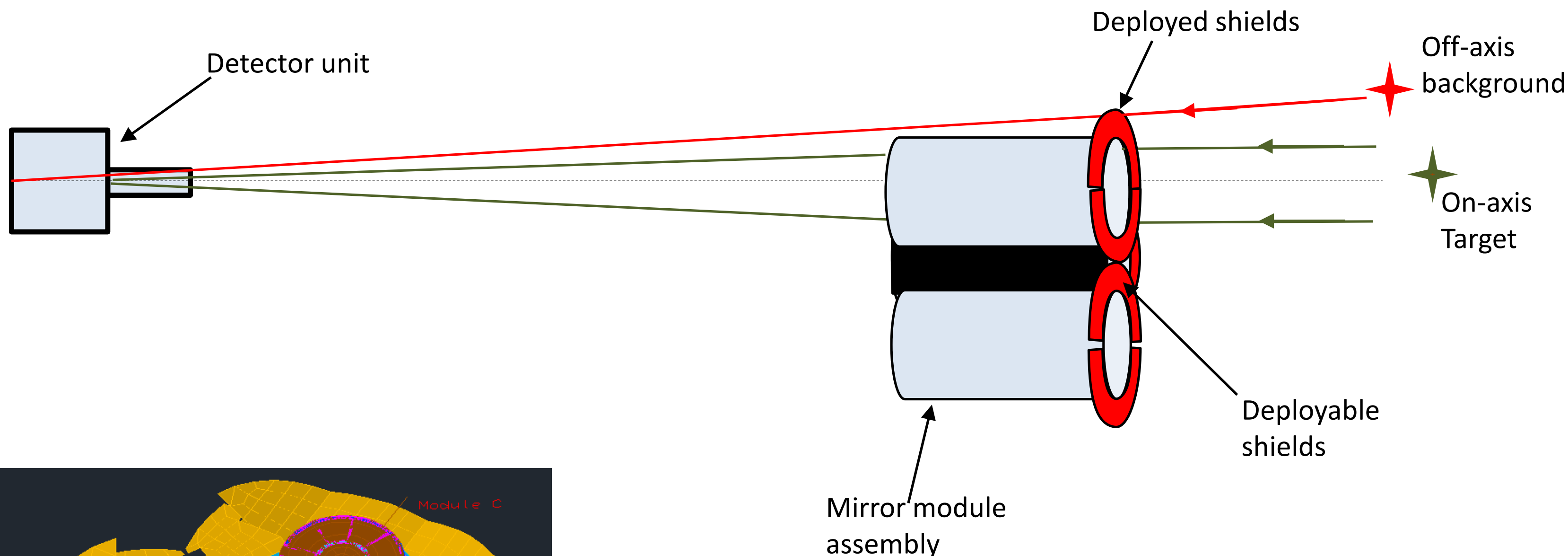
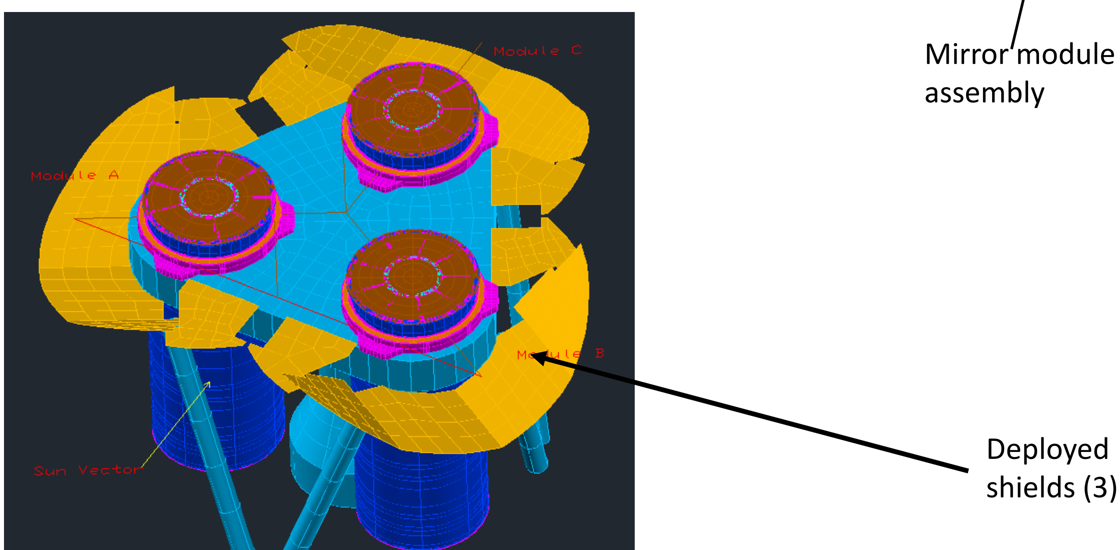
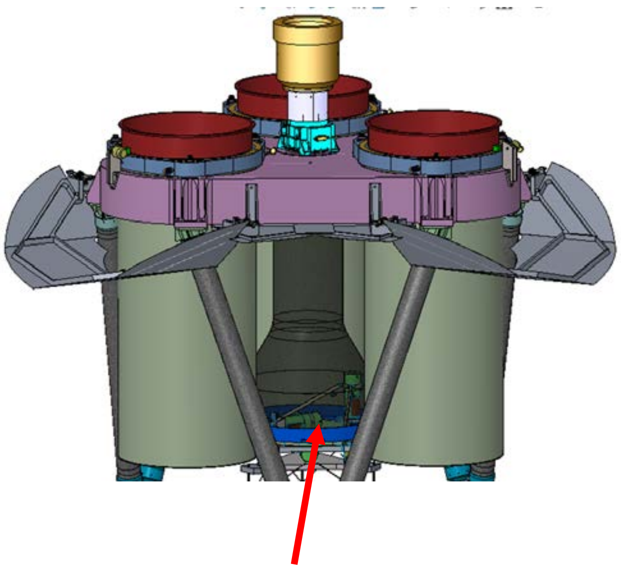
X-RAY SHIELDS



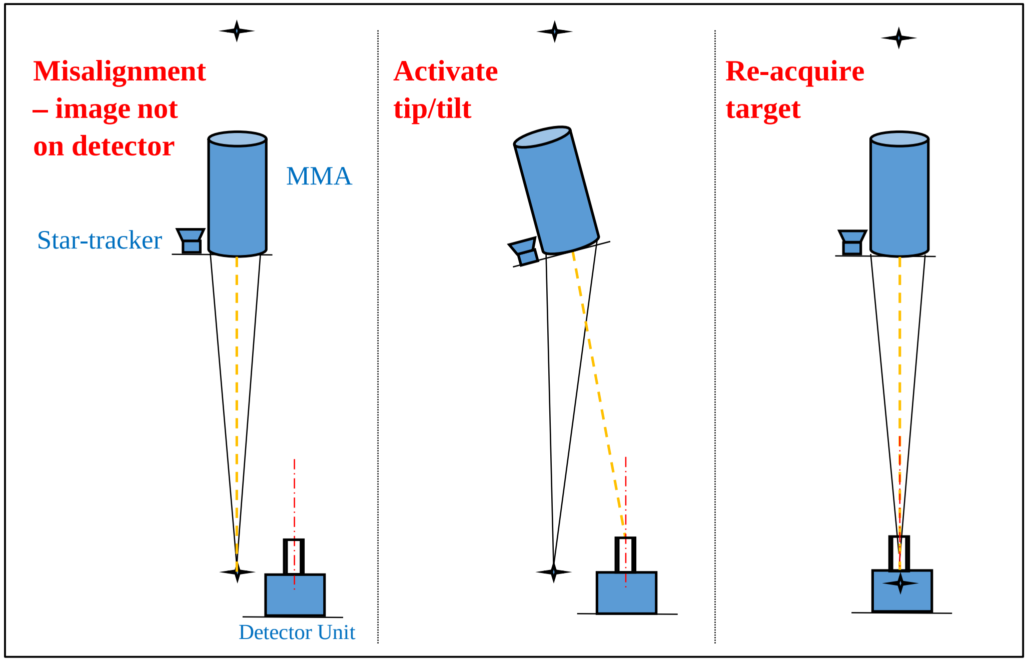


On-orbit Alignment

- If after deployment the Mirror Module Assemblies (MMAs) are out in translation, we would use a lookup table to tell us which tip/tilts to actuate and the amount of adjustment to apply

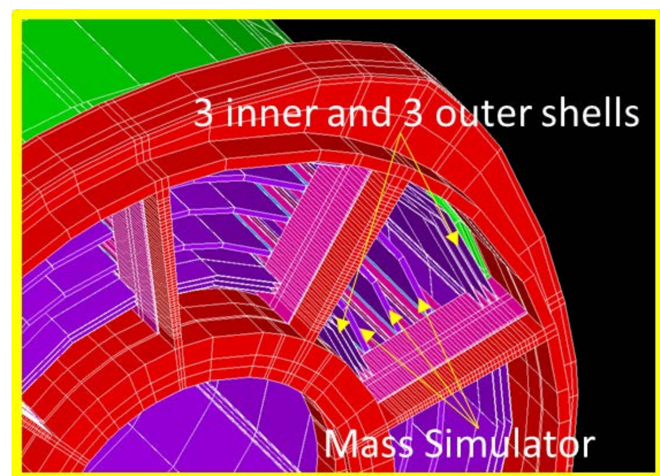


Tip/tilt/rotate adjustment
(on top of extending boom)



MMA Activities

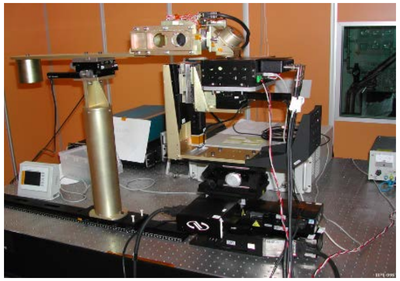
- **Build and test an engineering unit (in progress, completion in March 2018)**
  - Will have a subset of flight mirror shells
    - Will be used to:
      - *Exercise the whole fabrication and assembly process*
      - *Test all handling fixtures*
      - *Confirm the mechanical design through environmental testing*
      - *Provide a test system to verify procedures and hardware for the MMA and end-to-end ground calibration (along with a detector engineering unit).*



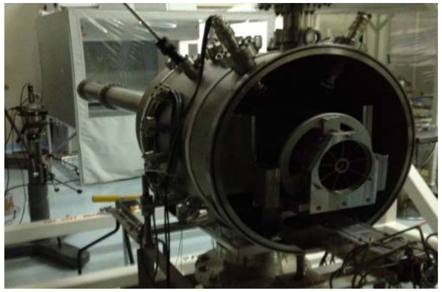
- **Build and test 4 flight units**
  - 3 Flight and 1 spare unit
    - Will all go through acceptance-level vibration tests
    - Will all be fully calibrated

X-RAY CALIBRATION

- **Plan**
  - Calibrate Detector Units (DU) in Italy at INAF/IAPS
  - Calibrate Mirror Module Assemblies (MMA) at MSFC
  - Perform end to end calibration at MSFC
    - Preparations with engineering units of MMA and DU
    - Allows test of SOC systems
- **Calibration Heritage**
  - MSFC: Chandra, ART-XC, FOXSI and HERO calibration
  - Italy: SXRP, BeppoSAX, Super AGILE, Fermi/LAT



Custom polarized sources for DU calibrations at IAPS



Stray-light test facility at MSFC

IXPE Schedule (under review)

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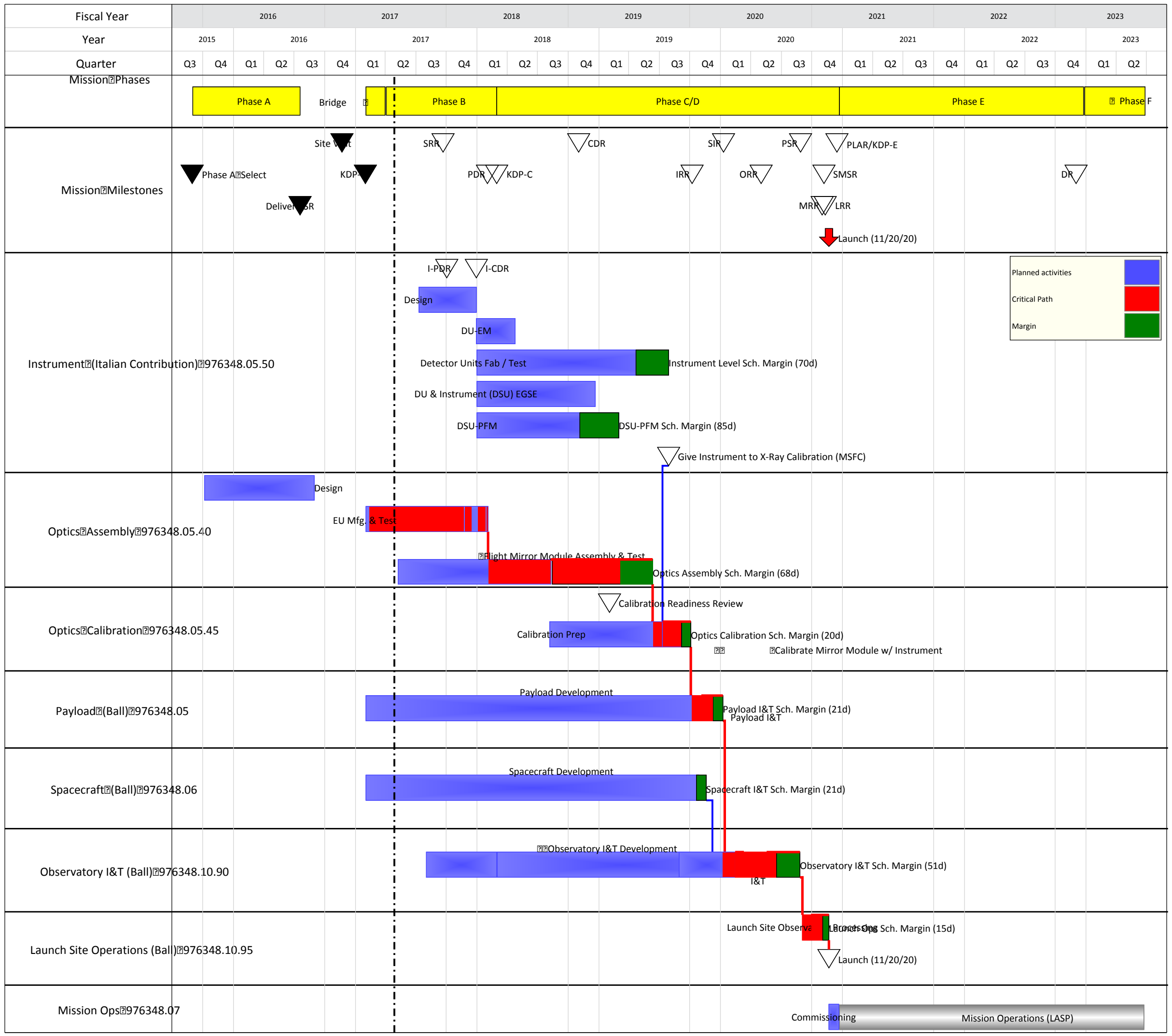

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